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Reporting Solid Particle Contamination in Helicopter Hydraulic Fluids

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ABSTRACT

This report recommends a method for reporting solid particle contamination for Australian Defence Force (ADF) helicopters and associated ground support equipment. Additionally, recommended limits for solid particle contamination are provided that can be used where no Original Equipment Manufacturer (OEM) advice exists or where the OEM advice is less conservative than the limits recommended herein.

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Executive Summary

This report discusses the two commonly used internationally recognised methods of reporting solid particle contamination in helicopter hydraulic systems. Both the International Standards Organisation (ISO) 4406 method and the Society of Automotive Engineers (SAE) Air Standard 4059 are discussed. The ISO 4406 method is recommended for reporting solid particle contamination in Australian Defence Force (ADF) helicopter hydraulic systems and associated ground support equipment. It is also recommended that all references to previous reporting methods be removed from oil sample reports and relevant publications to avoid confusion.

Additionally, recommended solid particle contamination limits for helicopter hydraulic systems and associated ground support equipment are presented. These limits are recommended for use where no Original Equipment Manufacturer (OEM) advice exists or where the OEM advice is less conservative than the limits recommended herein.

Contents

1. Introduction

The purpose of this report is to clarify the method for reporting ADF helicopter hydraulic system particle contamination. The way that particles are counted and reported has changed in recent years and this document aims to clarify this issue and recommend a reporting method for ADF helicopter hydraulic systems. It should be remembered that the primary aim of particle contamination reporting is to ensure the cleanliness of hydraulic systems and therefore minimise wear of components.

The Army Aviation Systems Program Office (AASPO) initially requested that DSTO provide advice regarding the method used to report solid particle contamination in CH-47D (Chinook) helicopter hydraulic systems, however, initial investigations revealed a need for a consistent method for all ADF helicopters. Whilst the reporting method recommended herein is applicable to ADF fixed wing aircraft, a separate investigation is required to determine suitable limits due to the different operating conditions.

2. Background

Hydraulic system solid particle contamination can come from either internal sources (i.e. metallic debris generated by the oil-wetted system) or external sources (i.e. environmental ingress of hard inorganic materials such as sand or dirt). Organic particles such as minute wear particles from seals or O-rings may also be present in the oil, however, whilst these particles are generally benign they may be indicative of an incipient failure. The purpose of solid particle counting in hydraulic systems is to ensure fluid cleanliness remains at a level that will minimise wear in components that have very fine manufacturing tolerances (i.e. hydraulic servo valves or pumps).

Prior to 2007, ADF aircraft hydraulic fluid particle contamination was generally reported in accordance with Australian Air Publication (AAP) 7027.002-1 [1]. This publication described a Royal Australian Air Force (RAAF) standard for particle contamination consisting of five particle size ranges combined with a RAAF class number that described the allowable count (per 100 ml sample) for each particle size range, as shown in Table 1.

Table 1: Historical RAAF Standard (obsolete) for Particle Contamination

RAAF Class	HIAC Particle Count per 100 ml					Notes
	5-15 µm	16-25 µm	26-50 µm	51-100 µm	100+ µm	
2	10 000	10 000	250	25	10	New fluid per MIL-H-5606
3	30 000	1 000	250	25	10	GSE per ASCC Air Standard 11/14D
4	60 000	6 000	1 500	225	50	Aircraft systems classes given in AAP 7027.002-1 are mandatory unless otherwise specified in the applicable aircraft AAP
5	100 000	10 000	3 000	500	50	
6	155 000	15 000	6 500	1 000	100	

The RAAF class system used the same particle size ranges as the National Aerospace Standard (NAS) 1638 system which was the basis of particle counting for many years. Both of these systems sized particles using a non-cumulative method; only particles within the specific range were counted, whereas a cumulative system typically reports all particles greater than a specific size. The RAAF class method is now obsolete and the relevant publication has been withdrawn.

As an example, hydraulic oil sample reports for Australian Army Chinook helicopters currently show three different reporting methods for solid particle contamination. This can be difficult for maintenance staff to decipher and is an unnecessary complication. Further, the extant limits for solid particle contamination in this particular helicopter [2] do not have a clear provenance and use a method that is not aligned with any of the common historical methods for reporting solid particle contamination. Table 2 shows the extant Chinook solid particle contamination limits.

Table 2: Extant Solid Particle Contamination Limits for Australian Army CH-47D helicopters

	Particle Contamination Level						
	Acceptable						**Unacceptable**
Micron Size Range	0	1	2	3	4	5	**6**
5-10	2 700	4 600	9 700	24 000	32 000	87 000	128 000
10-25	670	1 340	2 680	5 360	10 700	21 400	42 000
25-50	93	210	380	780	1 510	3 130	6 500
50-100	16	28	56	110	225	430	1 000
Over 100	1	3	5	11	21	41	92
Total	3 480	6 181	12 821	30 261	44 456	112 001	177 592

In recent years two new standards have emerged that report the cumulative results of solid particle counting and are discussed in more detail below. Both of the new standards were designed to be used with Automatic Particle Counters (APC).

2.1 Calibration

Historically, particle counting instruments were calibrated using Air Cleaner Fine Test Dust (ACFTD) with a particle size distribution determined by measurement using an optical microscope. The measurement of particle size for ACFTD was based on the maximum chord length of a particle (also known as the maximum calliper diameter). In the 1990's ACFTD production ceased and a replacement was sought. Additionally the control of particle size distribution from batch to batch was not adequate by modern standards. The International Standards Organisation (ISO) then requested that the National Institute of Standards and Technology (NIST) produce a standard reference material to be used for calibrating APCs. This new reference material consisted of ISO Medium Test Dust (ISO MTD) suspended in hydraulic fluid that had a traceable and known particle size distribution. The traceability of ISO MTD was required to meet the requirements if the ISO 9000 quality management system.

The particle size distribution of ISO MTD is determined using a Scanning Electron Microscope (SEM) with image analysis software, which is a significant improvement over the previous optical microscopy method. A key difference between the old and new methods is that a different measurement is used to define the size of a particle. Previously the maximum chord length of a particle was used, whereas the new SEM-based system measured the projected area equivalent diameter of a particle. It was discovered that the earlier method substantially underestimated the number of particles less than approximately 10 µm. The ISO 11171 standard [3] was created to describe how APCs should be calibrated using the new calibration reference material. It is important to realise that only the method of measuring changed and not the physical dimensions of real particles being measured. Table 3 shows a comparison of the recorded size for particles using the optical microscopy chord measurement and the projected area equivalent diameter.

Table 3: Comparison of particle measurements

Optical microscope measurement of particle chord length	SEM measurement of projected area equivalent diameter
1 µm	4 µm(c)
5 µm	6 µm(c)
10 µm	10 µm(c)
15 µm	14 µm(c)

In order to recognise that an APC had been calibrated using the new measurement method (i.e. in accordance with ISO 11171), the measurement unit was designated µm(c). This unit simply indicates that the particles are measured in microns by an APC that has been calibrated in accordance with ISO 11171.

3. Current Standards

3.1 ISO 4406

The ISO 4406 [4] standard describes a cumulative method for reporting solid particle contamination in hydraulic fluids measured by APCs. It consists of a simple cleanliness code consisting of three code numbers that define the cumulative number of particles greater than or equal to 4 µm(c), 6 µm(c) and 14 µm(c) respectively. The three numbers are written sequentially and separated by a forward slash. The scale numbers relate to a particle count range that approximately doubles between consecutive scale numbers as illustrated in Table 4. It should be noted that this standard refers to the number of particles per millilitre and not per 100 ml (as per previous standards).

Table 4: Extract of ISO 4406 Scale Numbers

ISO 4406 Scale number	Number of particles (per ml)	
	More than	**Up to and including**
>28	2 500 000	
28	1 300 000	2 500 000
27	640 000	1 300 000
26	320 000	640 000
25	160 000	320 000
24	80 000	160 000
23	40 000	80 000
22	20 000	40 000
21	10 000	20 000
20	5 000	10 000
19	2 500	5 000
18	1 300	2 500
17	640	1 300
16	**320**	**640**
15	160	320
14	**80**	**160**
13	40	80
12	**20**	**40**
11	10	20
10	5	10
9	2.5	5
8	1.3	2.5

As an example, Table 5 shows what a typical ISO cleanliness code means in terms of particle counts. No interpretation of the ISO 4406 cleanliness code is generally required since operators simply ensure that all of the three numerals reported for a sample are less than or equal to the corresponding system target cleanliness code (i.e. limit). Table 6 shows some example data and how the ISO cleanliness code would flag a contamination problem.

Table 5: Interpretation of a typical ISO cleanliness code

		1st scale number	**2nd scale number**	**3rd scale number**
ISO Cleanliness Code		16	14	12
Interpretation	Number of particles per ml	More than **320** and less than or equal to **460**	More than **80** and less than or equal to **160**	More than **20** and less than or equal to **40**
	Size	Greater than or equal to **4 μm(c)**	Greater than or equal to **6 μm(c)**	Greater than or equal to **14 μm(c)**

Table 6: Example of ISO cleanliness code operation

Sample	Sample ISO Cleanliness Code	System Limit	Limit Exceeded?
1	16/12/10	18/16/14	No
2	**19**/16/14	18/16/14	**Yes, because 19>18**
3	**20**/**19**/16	18/16/14	**Yes, because 20>18 and 19>16**

It should be noted that this system has an inherent self-checking feature since the numbers must descend when read from left to right. For example, first code number cannot be less than the second code number since the first code number reports all particles greater than or equal to 4 µm(c).

3.2 SAE AS4059

The Society of Automotive Engineers (SAE) Air standard 4059 [5] also describes a cumulative method for reporting solid particle contamination in hydraulic systems. The primary difference is that this standard defines the number of particles in three more ranges for larger particles compared to the ISO 4406 method. The SAE AS4059 method also uses an alpha-numerical code to identify the relevant particle size range (alpha component) and the cleanliness class (numerical component). It is important to note that this method refers to particle counts per 100 ml sample (and not per ml as in ISO 4406). Table 7 shows an extract of the SAE AS4059 cleanliness level code.

Table 7: SAE AS4059 Codes

		Maximum contamination limits (particles/100 ml)					
Size, ISO 11171 calibration or electron microscope		>4 µm(c)	> 6 µm(c)	>14 µm(c)	>21 µm(c)	>38 µm(c)	>70 µm(c)
Size code		**A**	**B**	**C**	D	E	F
Classes	000	195	76	14	3	1	0
	00	390	152	27	5	1	0
	0	780	304	54	10	2	0
	1	1560	609	109	20	4	1
	2	3120	1220	**217**	39	7	1
	3	6250	2430	432	76	13	2
	4	12 500	**4 860**	864	152	26	4
	5	25 000	9 730	1 730	306	53	8
	6	**50 000**	19 500	3 460	612	106	16
	7	100 000	38 900	6 920	1 220	212	32
	8	200 000	77 900	13 900	2 450	424	64
	9	400 000	156 000	27 700	4 900	848	128
	10	800 000	311 000	55 400	9 800	1 700	256
	11	1 600 000	623 000	111 000	19 600	3 390	512
	12	3 200 000	1 250 000	222 000	39 200	6 780	1020

Table 8: Interpretation of an SAE AS4059 cleanliness code

SAE cleanliness class		6A	4B	2C
Interpretation	Number of particles per 100 ml	More than **25 000** and less than or equal to **50 000**	More than **2430** and less than or equal to **4860**	More than **109** and less than or equal to **217**
	Size	Greater than **4 µm(c)**	Greater than **6 µm(c)**	Greater than **14 µm(c)**

An SAE AS4059 cleanliness code 6A/4B/2C would be interpreted as shown in Table 8 and would be approximately equivalent to an ISO code of 16/13/8. A precise equivalent is not possible since the range of particle counts differs between standards. For example in SAE AS4059 class 6 has between 250 and 500 particles per ml, whereas ISO 4406 code 16 has between 320 and 640 particles per ml.

4. Recommended Hydraulic Fluid Solid Particle Contamination Reporting Method

Both of the modern standards described herein are internationally recognised and could be used on ADF helicopter hydraulic systems. Commercial laboratories offer reporting to either standard, however the ISO standard appears to be more widely used. Given the level of filtration in ADF helicopter hydraulic systems ranges between 5 micron and 10 micron absolute, there appears to be little reason to use the SAE AS4059 standard and its accompanying larger size ranges. The particles in the larger size ranges are still counted when using the ISO 4406 method, however they are simply reported as part of the cumulative three number code.

Another advantage of ISO 4406 is the intrinsic simplicity of assessing the code against a system limit (simply a numerical comparison); assessing SAE AS4059 limits is considered to be marginally less intuitive because of the alpha-numeric code.

It is therefore recommended that the ISO 4406 method for coding the level of contamination by solid particles be adopted as the standard reporting method for ADF aviation hydraulic systems (including ground support equipment). The ISO code provides a convenient method for operators to check that the hydraulic system is not contaminated by solid particles. Once adopted, all references to historical reporting methods (such as NAS 1638 or RAAF Class) should be removed from oil sample reports and manuals to avoid confusion. DSTO are able to assist in reviewing ISO 4406 limits for specific platforms if required.

5. Application to Equipment

5.1 Helicopter Hydraulic Systems

Where specific guidance is not supplied by the aircraft OEM, the ISO code 20/17/13 is recommended as the target cleanliness level for ADF helicopter hydraulic systems; this level of solid particle contamination should not be exceeded. Where OEM guidance allows for a greater level of solid particle contamination, the limit recommended herein (20/17/13) should take precedence.

This limit has been determined by taking the average of several conversions and statistical analyses as shown in Table 9. Approximate conversions to ISO 4406 codes were calculated for the following historical reporting methods:

1. RAAF Class 4: this was selected for conversion as it was the cleanest level for aircraft systems under that now obsolete system.
2. DEF STAN 05-42/2: Code 1300F from this standard was selected as it was recommended for aircraft flight control systems [6].
3. NAS 1638: Class 8 from this standard has traditionally been used for aircraft such as the Black Hawk [7] as the maximum in-service limit and was therefore included for conversion.
4. Extant CH-47D Limits: Although the provenance of the published limits for Australian Army CH-47D helicopters is unknown, Class 6 (unacceptable) was converted and included in the determination of the recommended ADF limit.

It should be noted that the conversions from all of the above standards are approximate and an equivalent limit for the ≥4 μm(c) ISO 4406 code number cannot be determined since none of the earlier standards contain particle counts for the 1 μm to 5 μm range.

In addition to the conversion calculations, a statistical analysis was conducted on a sample of Australian Army CH-47D helicopters (43 samples) and Royal Australian Navy Sea King helicopters (61 samples). In both cases the statistical limit was determined by adding one standard deviation to the average.

Appendix A contains all conversion calculations and statistical data used in determining the recommended limit. A summary of the conversions and analysis appears in Table 9.

Table 9: Summary of conversions to ISO 4406

Source	ISO 4406 codes		
	≥4 μm(c)	≥6 μm(c)	≥14 μm(c)
Conversion of RAAF Class 4*	-	17	13
Conversion from DEF STAN 05-42 Code 1300F*	-	16	11
Conversion of NAS 1638 Class 8*	-	17	14
Conversion of CH-47D Class 6 (unknown provenance)*	-	18	16
Statistical analysis of CH-47D samples	19	16	12
Statistical analysis of Sea King samples	21	17	13
Recommended Target Cleanliness Level for ADF Helicopter Hydraulic Systems (Average conversions and statistical analyses)	**20**	**17**	**13**

* It is not possible to produce an ISO 4406 code for particles >4 μm(c) from these sources.

5.2 Ground Support Equipment

Ground Support Equipment (GSE) such as hydraulic system power carts must provide hydraulic fluid cleaner than the aircraft system, otherwise contamination is introduced to the aircraft when the equipment is connected and used. In order to determine a suitable ISO code for ground support equipment, conversions were conducted from RAAF Class 3 (identical to DEF STAN 17-5/2 [8] for ground support equipment). Appendix B shows the conversion calculations. The conversion results in an ISO code -/15/11. Whilst it was not possible to do a conversion for particles >4 μm(c), a value for this particular cumulative size range was derived by subtracting two ISO code numbers from the recommended ADF helicopter code detailed in section 5.1. The second and third code numbers (converted from DEF STAN 17-5/2) are also two ISO codes below the recommended ADF helicopter code. The recommended ISO code for ground service equipment is therefore 18/15/11.

The recommended ISO 4406 code for GSE in this report supersedes any previous DSTO advice [9].

6. Recommendations

This report recommends that:

1. The ISO 4406 method for coding the level of contamination by solid particles be adopted as the standard reporting method for ADF helicopter hydraulic systems;
2. Once ISO 4406 has been adopted, all historical reporting methods be removed from oil sample reports and applicable manuals to avoid confusion;
3. In the absence of specific guidance from aircraft OEMs, the in-service limit for hydraulic fluid solid particle contamination be set at **20/17/13**;
4. In the absence of specific guidance from aircraft OEMs, the maximum level of solid particle contamination for ground service equipment be set at **18/15/11**;
5. The ISO 4406 method be considered by the Joint Fuels and Lubricants Agency as the standard reporting method for all other ADF platforms; and
6. The DSTO Fuel and Lubricants group be engaged to convert platform-specific OEM limits if required.

7. References

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2. Royal Australian Air force Australian Air Publication 7210.009-2-15, CH-47D Chinook Maintenance Manual – Condition Monitoring, Annex A Table 1, 31 May 2001.
3. ISO 11171:1999, Hydraulic Fluid Power - Calibration of Automatic Particle Counters for Liquids, 1999.
4. ISO 4406:1999(E), Hydraulic Fluid Power – Fluids – Method for Coding the Level of Contamination by Solid Particles, 2nd edition, 1 December 1999.
5. SAE AS4059, Aerospace Fluid Power – Cleanliness Classification for Hydraulic Fluids, Revision D, April 2001.
6. DEF STAN 05-42/2, Particulate Contamination Classes for Fluids in Hydraulic Systems, paragraph A.9, 13 May 1982.
7. Snyder, E. (U.S. Air Force Research Laboratory), Air force Hydraulic Systems Fluid Sampling Program Contamination Results, presentation at the 44th Air & Space Interoperability Council, January 2006.
8. DEF STAN 17-5/2, Power Driven Hydraulic Ground Servicing Equipment for Aircraft, paragraph 4.2, 10 April 1986.
9. Rawson, P., RAAF Ground Support Equipment Hydraulic Fluid Service Life and Condition, DSTO-CR-2006-0050, 7 March 2006.

Appendix A: Determination of ADF Aircraft Hydraulic System Solid Particle Contamination Limit

A.1. Conversion of RAAF Class 4 to ISO 4406

The following method was used to determine an approximate ISO 4406 code for RAAF class 4. Table 10 shows the particle distribution for RAAF Class 4 (non-cumulative).

Table 10: RAAF Class 4 Solid Particle Contamination Limits

	Maximum particle counts per 100 ml				
RAAF Class	5-15	16-25	26-50	51-100	>100
4	60 000	6 000	1 500	225	50

To convert to ISO the cumulative total was determined as follows:

Total Particles > 5 µm (6 µm(c)) = 60 000+6 000+1 500+225+50
= 67775 / 100 ml
= 678/ml
→ ISO code number: 17

Total Particles > 15 µm (14 µm(c)) = 6 000+1 500+225+50
= 7775 / 100 ml
= 78/ml
→ ISO code number: 13

Note: it is not possible to determine an equivalent count for particles > 4 µm(c)
Therefore the approximate ISO code for RAAF Class 4 = -/17/13

A.2. Conversion of DEFSTAN 05-42 1300F to ISO 4406

The following method was used to determine an approximate ISO 4406 code for DEF STAN 05-42/2 Class 1300F. Table 11 shows the particle distribution for DEF STAN 05-42 Class 1300F (cumulative).

Table 11: DEF STAN 05-42/2 Code 1300F Solid Particle Contamination Limits

	Maximum particle counts per 100 ml	
DEF STAN class	> 5 µm	> 15 µm
1300F	41 000	1 300

Note: it is not possible to determine an equivalent count for particles > 4 µm(c)
Therefore the approximate ISO code to DEF STAN 1300F = -/16/11

A.3. Conversion of NAS 1638 Class 8 to ISO 4406

The following method was used to determine an approximate ISO 4406 code for NAS 1638 Class 8. Table 12 shows the particle distribution for NAS 1638 Class 8 (non-cumulative).

Table 12: NAS 1638 Class 8 Solid Particle Contamination Limits

	Maximum particle counts per 100 ml				
NAS 1638	5-15	15-25	25-50	50-100	>100
Class 8	64 000	11 400	2 025	360	64

To convert to ISO the cumulative total was determined as follows:

Total Particles > 5 µm (6 µm(c)) = 64 000+11 400+2 025+360+64
= 77 849 / 100 ml
= 778/ml
→ ISO code number: 17

Total Particles > 15 µm (14 µm(c)) = 11 400+2 025+360+64
= 13 849 / 100 ml
= 138/ml
→ ISO code number: 14

Note: it is not possible to determine an equivalent count for particles > 4 µm(c)
Therefore the approximate ISO code for NAS 1638 Class 8 = -/17/14

A.4. Conversion of CH-47D Limits to ISO 4406

The limits for solid particle contamination in the hydraulic systems of the Australian Army CH-47D helicopter are published in Annex A to AAP 7210.009-2-15. The non-cumulative particle size ranges are reproduced below. The provenance of these limits is not known and the first two particle size ranges (5-10 µm and 10-25 µm) do not match those of any of the common historical reporting standards. The commonly used size ranges were 5-15 µm and 15-25 µm. The impact of this is a slight underestimation of the particles >15 µm (≥14 µm(c)) since this would normally be accomplished by a cumulative count of particles commencing with the 15-25 µm range. Despite this inherent error, the extant limits were converted and included in the final limit determination. A sensitivity analysis was conducted and removal of this conversion did not alter the final recommended target cleanliness level shown in Table 9.

In the published CH-47D limits, Class 6 is considered *Unacceptable*. To convert to an approximate ISO 4406 code the cumulative total was determined as follows:

Total Particles > 5 μm (6 μm(c)) = 128 000 + 42 000 + 6 500 + 1 000 + 92
= 177 592 /100 ml
= 1776/ml
→ ISO code number: 18

Total Particles > 15 μm (14 μm(c)) = 42 000+6 500+1 000+92
= 49 592 / 100 ml
= 496/ml
→ ISO code number: 16

Note: it is not possible to determine an equivalent count for particles > 4 μm(c)
Therefore the approximate ISO code for CH-47D Class 6 = -/18/16

A.5. Statistical Analysis of Australian Army CH-47D Samples

Table 13: Extract of Australian Army CH-47D Hydraulic System Solid Particle Contamination Results

CH-47D Sample Note: Samples taken between February 2007 and June 2009	**ISO 4406 Code**		
	≥4 μm(c)	**≥6 μm(c)**	**≥14 μm(c)**
1	14	12	9
2	14	12	7
3	16	14	11
4	17	14	9
5	14	11	6
6	16	13	10
7	20	17	13
8	21	19	16
9	15	12	8
10	13	10	7
11	13	10	6
12	15	12	8
13	13	11	7
14	14	12	7
15	15	13	9
16	11	9	7
17	18	14	9
18	15	11	6
19	13	11	8
20	16	13	10
21	18	16	10
22	16	14	10
23	16	14	8
24	20	18	13
25	17	15	9
26	16	13	8
27	18	15	11
28	15	14	11

CH-47D Sample Note: Samples taken between February 2007 and June 2009	ISO 4406 Code		
	≥4 µm(c)	≥6 µm(c)	≥14 µm(c)
29	17	14	11
30	17	16	13
31	20	15	11
32	16	14	10
33	18	16	12
34	21	20	16
35	15	13	10
36	16	14	10
37	12	10	6
38	13	10	6
39	14	10	7
40	20	16	10
41	12	10	5
42	16	12	6
43	19	17	13
Average	16	13	9
Standard Deviation (rounded)	3	3	3
Average + 1 S.D.	**19**	**16**	**12**

A.6. Statistical Analysis of Royal Australian Navy Sea King Samples

Table 14: Extract of Royal Australian Navy Sea King Hydraulic System Solid Particle Contamination Results

Sea King Sample Note: Samples taken between 2008 and 2009	ISO 4406 Code		
	≥4 µm(c)	≥6 µm(c)	≥14 µm(c)
1	20	16	12
2	17	15	12
3	17	14	11
4	19	14	10
5	19	15	13
6	18	16	13
7	19	16	12
8	19	17	13
9	18	15	12
10	20	17	13
11	20	15	11
12	18	13	10
13	17	14	10
14	18	15	11
15	19	17	15
16	20	18	15
17	16	14	11
18	17	15	12
19	19	16	12
20	18	16	13
21	17	15	11
22	20	17	11
23	22	16	11

Sea King Sample Note: Samples taken between 2008 and 2009	**ISO 4406 Code**		
	≥4 µm(c)	**≥6 µm(c)**	**≥14 µm(c)**
24	18	15	11
25	20	16	12
26	17	15	11
27	17	14	11
28	21	17	12
29	15	13	10
30	16	13	10
31	19	17	12
32	21	18	15
33	19	16	13
34	17	15	12
35	20	17	12
36	21	17	11
37	17	14	9
38	19	15	11
39	19	16	11
40	17	15	12
41	19	16	12
42	20	18	13
43	17	15	11
44	20	17	11
45	18	16	11
46	19	16	14
47	20	17	13
48	21	16	12
49	17	14	11
50	22	18	12
51	16	14	12
52	17	15	12
53	16	13	8
54	21	18	14
55	20	17	13
56	18	15	11
57	18	15	12
58	18	16	13
59	21	16	12
60	23	17	11
61	21	17	12
Average	19	16	12
Standard Deviation (rounded)	2	1	1
Average + 1 S.D.	**21**	**17**	**13**

Appendix B: Determination of Ground Support Equipment Solid Particle Contamination Limit

The following method was used to determine an approximate ISO 4406 code for RAAF class 3 applied to ground service equipment for hydraulic systems. Table 15 shows the particle distribution for RAAF Class 3 (non-cumulative and equivalent to DEF STAN 17-5/2).

Table 15: RAAF Class 3 Particle Limits

	Maximum particle counts per 100 ml				
RAAF Class	5-15	16-25	26-50	51-100	>100
3	30 000	1 000	250	25	10

To convert to ISO the cumulative total was determined as follows:

Total Particles > 5 µm (6 µm(c)) = 30 000+1 000+250+25+10
= 31285 / 100 ml
= 313/ml
→ ISO code number: 15

Total Particles > 15 µm (14 µm(c)) = 1 000+250+25+10
= 1285 / 100 ml
= 13/ml
→ ISO code number: 11

Note: it is not possible to determine an equivalent count for particles > 4 µm(c)
Therefore the approximate ISO code for RAAF Class 3 = -/15/11

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Helicopter, hydraulics, contamination

19. ABSTRACT

This report recommends a method for reporting solid particle contamination for Australian Defence Force (ADF) helicopters and associated ground support equipment. Additionally, recommended limits for solid particle contamination are provided that can be used where no Original Equipment Manufacturer (OEM) advice exists or where the OEM advice is less conservative than the limits recommended herein.